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A Blended Laboratory-Based Learning Model for Embedded Systems Education

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Abstract

This research aims to develop a blended learning model tailored for laboratory instruction in embedded systems education. The proposed model is designed to replace traditional instructional methods, which often lack opportunities for reflection and fail to motivate learners sufficiently. Initially, the research identified existing challenges in teaching and learning practices and the core competencies required of undergraduates for the embedded systems. Subsequently, a blended laboratory-based learning model was designed to enhance students' practical skills in alignment with Industry 4.0 demands. Classroom action research was employed as the framework for developing the PPED model, encompassing four steps: planning, practice, assessment, and discussion. The instructional package included a teacher's manual, an experimental kit, simulation software, worksheets, and assessment tests. The study sample comprised undergraduate students enrolled in the Digital Circuit Design course within the Department of Information and Communication Engineering, at the Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University. Findings indicated that the quality of the instructional package was rated as highly appropriate by both experts and students. Furthermore, the PPED model's quality was assessed as highly relevant for laboratory learning. The PPED model's efficiency met the established standard criteria based on process and outcome performance evaluation, passing the E1/E2 standard with scores of 74.38% and 72.29%, respectively. Additionally, student satisfaction with the instructional package was rated as very high. This research highlights the integration of diverse teaching methods and innovative instructional media, emphasizing active learning engagement in the educational process. The PPED model supports knowledge and experience construction through hands-on activities, fostering behavioral change, enriching students' learning experiences, and promoting lifelong learning skills. In conclusion, the study underscores the importance of modernizing instructional approaches by integrating educational technology and diverse pedagogical methods within a conducive classroom environment. Such a blended laboratory-based learning approach is crucial for advancing educational practices to meet the demands of 21st-century learners in an ever-evolving learning world.

1. Introduction

Transitioning from the old Industrial Revolution world to the digital world caused the needs of the labor market to change. Various skills that are repeated are not enough anymore because a computer can do it. As the world changes so quickly that people sometimes cannot keep up, the world of learning also does not end with the classroom anymore. (Boltsi et al. 2024) The 21st century skills therefore play an important role in enabling learners to keep up with the world and be able to survive in a rapidly changing world. The 21st-century skills are a new form of education that is not just learning for exams but is learning to be further developed for living in a society that is driven and changing rapidly. The 21st-century skills consist of 3 main learning subjects and 16 learning skills, as shown in Fig. 1. According to the World Economic Forum (WEF), the organization has surveyed needs and analyzed demand from labor markets around the world It answers the question of life skills appropriate to the context of today's world, skills in dealing with life's challenges, and skills for dealing with a rapidly changing world. The processes used to build these skills cannot be created from those used in a traditional classroom. The teaching style must therefore be emphasized by considering the role of the learner (World Economic Forum, 2015). WEF has further analyzed that it must be a process of what kind of teaching media will be able to drive the creation of social & emotional skills that directly lead to skills in the 21st century. The results indicate that there are 3 main forms of the process the following is a format that will work well: structure of interactions is a process that creates repeated and continuous engagement with the lesson to create repeated training until it becomes a skill, elements of the play is a process that has a mechanism that can respond and change the results according to the different decisions of the learner, and assessment and reinforcement is a process that includes giving feedback, measuring results, and providing guidance and coaching to learners. For learners to learn the correct way and can immediately adjust in the wrong direction. Learning skills in the 21st century is, therefore, an important process for enhancing collaborative learning among school administrators, teachers, and learners that are consistent with the thinking framework that the learning process is more important than knowledge, and the process of finding answers is more important than the answer. It is a learning skill for use in developing an educational curriculum or an environment in an institution that emphasizes learners having professional qualifications or professional skills (Khaemmanee, 2021), (Martinez, 2022).

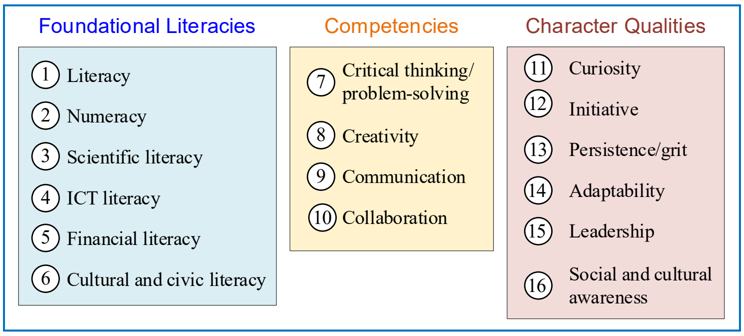

Fig. 1 *The importance of 21st-century skills of the World Economic Forum (WEF)*

The skills required in the 21st century align closely with the professional competencies essential for the era of Industry 4.0, or the Fourth Industrial Revolution. This era is characterized by a shift in manufacturing and processing industries toward greater automation, utilizing advanced and cutting-edge technologies. A critical component of Industry 4.0 is the integration of communication technologies among machines, along with the Internet of Things (IoT), to enhance the productivity and efficiency of automated systems. Globally, Industry 4.0 initiatives are being adopted under various national programs, each reflecting localized approaches to innovation in manufacturing. For instance, the United States promotes "Smart Manufacturing," while the European Union has developed the "Factories of the Future" (FoF) initiative. Germany's "Industry 4.0" and Japan's "Industrial Value Chain Initiative" (IVI) represent similar movements, alongside "Manufacturing Innovation 4.0" in South Korea, "A New Era in Chinese Manufacturing" in China, and "Productivities 4.0" in Taiwan. In Southeast Asia, Singapore and Malaysia are at the forefront of Industry 4.0 adoption (Ciolacu et al., 2023). Singapore's factory model serves as a prototype for CLMV nations (Cambodia, Laos, Myanmar, and Vietnam), whereas Malaysia emphasizes advancements in information technology. Thailand's approach, articulated in the Thailand 4.0 policy (Wicha et al., 2023), focuses on developing technology and industrial clusters to support the future economy. The Thai industrial sector must be prepared to transition from a traditional economy to an innovation-driven economy that emphasizes high-value production. The goals of the Thailand 4.0 policy include fostering economic growth, achieving high-income status with less resource dependence, reducing socio-economic disparities, and promoting economic and social balance through innovative products rather than traditional commodities. Achieving these objectives necessitates a workforce with specialized, high-level skills in innovation and technology. A strategic approach to education is critical to developing a workforce capable of driving high-value innovation. Educational management systems must prioritize the development of personnel with the skills necessary for innovation. Professional competencies for the 21st century should be emphasized, including creativity, innovation, scientific and technological literacy, and research and development capabilities. These competencies serve as foundational elements for fostering competitive advantages within the five key technology groups and targeted industries of the future (see Fig. 2).

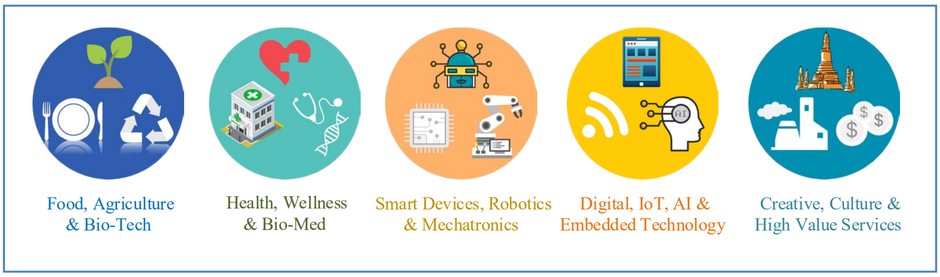

Fig. 2 *Technology and target industries in the 4.0 era*

In the era of Industry 4.0, the core technology groups and target industries include (1) food, agriculture, and biotechnology; (2) health, wellness, and biomedicine; (3) smart devices, robotics, and mechatronics; (4) digital, Internet of Things (IoT), artificial intelligence (AI), and embedded technology; and (5) the creative industry, culture, and high-value service sectors. Among these, digital, AI, and embedded technologies are particularly crucial today, as they drive technology disruption and transformation across industries. Embedded technology, which encompasses various electronic devices and appliances, plays an increasingly influential role in daily life. Embedded systems are essential in the development of smart electronic devices, fulfilling diverse needs and aligning with consumer and industry demand for advanced functionalities. Thailand, as a major global production and export base for electrical appliances and electronics, is strategically positioned to become a global center for automated system manufacturing. In line with the Industry 4.0 agenda and the Thailand 4.0 vision, there is a high demand within the industry for skilled professionals with expertise in embedded systems. This need has driven educational institutions to revise and adapt curricula to better reflect industry demands and stakeholder expectations. Programs in electrical and electronic engineering, industrial education, technology, and related fields within Bachelor's programs have increasingly incorporated digital and embedded technology courses as foundational components, serving as a basis for advanced, specialized courses. Thus, it is essential to enhance the teaching and learning models, as well as the instructional technologies used in educational programs, to align with current and future developments in digital and embedded systems. This alignment will better prepare graduates to meet the needs of an evolving industry landscape shaped by rapid technological advancement.

2. Learning and Teaching Model Design

The Classroom Action Research (CAR) model was developed from a belief base that emphasizes research that integrates knowledge or action theory gained from actual fieldwork. Learning problems in the classroom will be successfully resolved through critical reflection on the work carried out as planned. This is an important guideline for successful learning management, which requires continuous development of teachers' teaching methods to solve problems or continually improve learning styles for better quality and efficiency (Singkorn et al., 2022). The CAR model is a reliable and systematic process carried out in conjunction with learning management. This is a normal job that teachers do to gain new knowledge or new methods to be used in learning management to solve problems arising from learning and teaching in the classroom or to develop learners' learning. Results from the CAR model will be used to improve learning and teaching processes or promote learners' learning. The CAR model must be implemented quickly to use the results immediately, reflect information about operations, and exchange knowledge on practices and results to improve the learning of both learners and teachers. The CAR process, popularly called P-A-O-R, consists of 4 steps; Plan (P) is a step in determining how to conduct research according to the objectives, population, and target groups, or who the sample group, how to carry out the research plan, what research tools are available, how to create research tools, as well as analyzing data and analyzing data, and how long the trial period is, etc. Action (A) is the process of carrying out the work according to the plan, Observation (O) is the process of observing the behavior of the learners that occurs through the research tools created and developed, Reflection (R) is the process of reflecting on achievements or issues that need to be resolved in research and including future research directions. The 4-step CAR model is a cycle, the learning process can take 2-3 cycles and usually ends when the researcher is finished or satisfied with the results.

Currently, educational arrangements have adopted teaching models and techniques to respond to the development of human resources capabilities and the country's competitiveness. The educational system focuses on in terms of advancements in technology, adapting to the distribution of knowledge, and linking diverse knowledge connected around the world. The literacy of information and communication technology in the education system is necessary and important, such as using computers as teaching equipment to using various services on the internet network, especially the World Wide Web, developing them as teaching media appropriately, and organizing teaching and learning through electronic systems using internet technology as a medium of communication among learners and teachers. The advantage is that learners can study without limitations in time and place, providing opportunities and equality in learning for learners, and learners can quickly exchange knowledge to create a learning society through electronic systems. The blended learning model is a new style of integrated learning under the trend of technological development. It is a learning and teaching style of integrating and adapting modern technologies with normal teaching to achieve advanced learning. The blended educational innovations both learning and teaching techniques, models, and media (Kemmis et al., 2014) are combined to achieve maximum efficiency in learning. Therefore, the learning process combines various learning models whether learning takes place in the classroom combined with learning outside the classroom where learners and teachers do not face each other using a variety of learning resources. Learning processes and activities occur through a variety of teaching and learning strategies. The teaching goal is to help learners achieve their learning goals. Six common blended learning models offer various instructional methods: (1) Face-to-Face Driver: Real-time learning with active student engagement. (2) Rotation Model: Alternating between online and in-person instruction. (3) Flex Model: Flexible in time, content, and teaching methods. (4) Online Lab: Conducted fully online with expert support. (5) Self-Blended: Self-directed learning combined with formal curricula. (6) Online Driver: Primarily online learning with teacher supervision (Suwathanpornkul, 2019). Therefore, teachers can apply these 6 learning styles in learning and teaching to suit the real situation for good results for current learning and teaching.

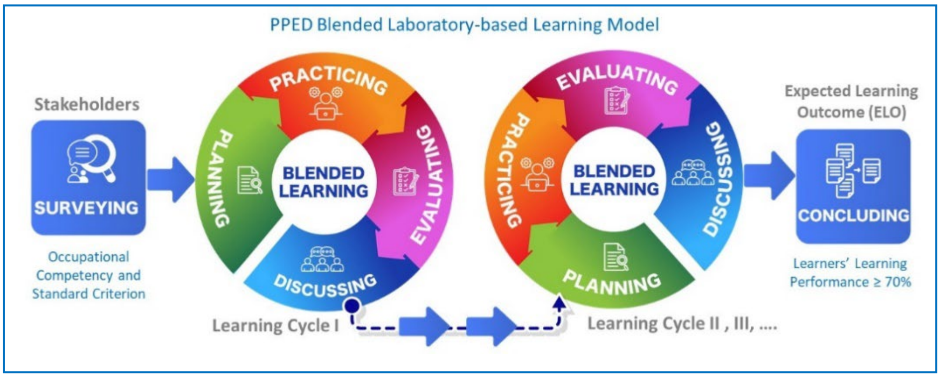

Fig. 3 *Schemes of the PPED learning model*

In studying the Industrial 4.0 policy and surveying industrial needs from executives, researchers, and engineers, it was found that the ability to produce a high level of labor to support the Industrial Revolution 4.0 is important. Learners should be encouraged to have hands-on skills and use modern technology teaching media. It integrates many types of knowledge and science and encourages students to be ready to work as a team, to have problem-solving skills, and to be able to create innovations so that learners have important skills that are in line with the needs of the industry (Tanyarattanasrisakul, 2022). From the above importance, it can be concluded that the classroom action research process and the blended learning process are used in learning and teaching. It will help teachers develop the quality of teaching and learning to suit the students' situations and be able to solve problems according to the set goals. Therefore, the development of modern teaching methods must emphasize student-centered learning. Many different sciences are integrated, with an emphasis on students being more hands-on and involved in teaching activities. In conducting this research, the researcher applied the action research process in the classroom along with blended teaching. There is a synthesis of appropriate teaching and learning models in specialized education to provide learners with learning skills in the 21st century and in line with labor standards for Industry 4.0 and as a guideline for developing higher education teaching using a learning model called the PPED learning model, as shown in Fig. 3., which consists of 6 processes, the steps are as follows.

• Step 1: Surveying is a process of surveying the problems of teaching and learning and the stakeholders' needs of the embedded industry to design appropriate teaching and learning formats and is a basis for developing learners' skills in line with Industry 4.0 and Thailand 4.0.

• Step 2: Planning is the process of determining the research objectives, population, target group, or sample group. How is the research plan carried out? What research tools are there? and proceed to create tools as well as how to analyze data and analyze data, how long is the trial period.

• Step 3: Practicing is the process of acting according to the plan that has been set. Emphasis is placed on integrated teaching and learning to create professional skills. Especially the application of software in the field of embedded systems.

• Step 4: Evaluating is the process of evaluating results obtained from work performance. Learner achievement is measured through a variety of measurement methods to examine changes in learner behavior according to the behavioral objectives set out in the curriculum.

• Step 5: Discussing is the process of discussing the results after knowing the results of the performance evaluation. To present the results of the study from the issues and prepare a plan to achieve the expected learning outcomes according to the standard framework of the course or to summarize the results of the next process.

• Step 6: Concluding is the process of summarizing the results obtained from the entire teaching and learning process and learning outcomes must cover both knowledge specialized skills and general skills according to the course standard framework.

3. Instructional Package Development

Design and development of a blended laboratory-based instructional package according to the PPED blended laboratory-based learning model process. This research is the design and creation of an instructional package on embedded systems and applications. The details are as follows.

3.1 Course Content Development

This research has focused on developing an instructional package for the subject of digital circuit design courses. Department of Information and Communication Engineering, Bachelor of Engineering Program, Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University. Emphasis is placed on developing learners' skills to apply embedded systems to support Industry 4.0 technology according to the expected learning outcomes standards of the curriculum according to the national higher education qualifications framework. Course description of digital circuit design. This course aims to study number systems and codes, logic operations and logic gates, Boolean algebra, logic reduction, combination logic circuits, memory components and data collectors, sequential circuits, sequential circuit analysis, and design, digital system design using programmable logic devices with CPLD and FPGA, VHDL language, modeling and simulation. Then use the content to develop an instructional package for developing skills in embedded system applications 4 topics: basic of LabVIEW Program and FPGA, combination logic circuits, sequential circuit analysis and design, and digital system design using programmable logic devices with CPLD and FPGA as shown in Fig. 4.

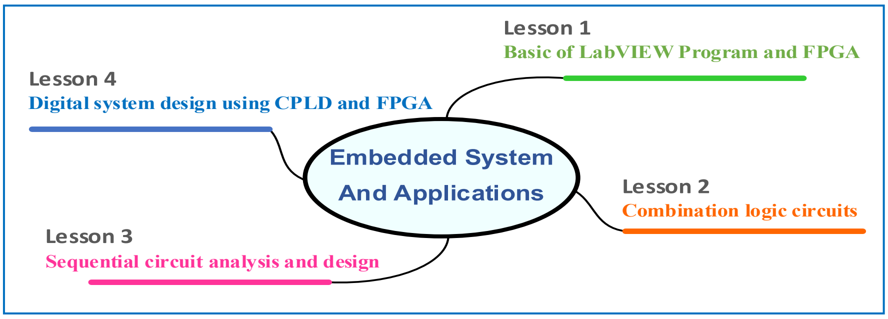

Fig. 4 *Course outline for embedded systems and applications*

The instructional package of the digital circuit design course was developed by emphasizing reference to the behavioral objectives of each lesson. The instructional package consists of course contents, a PowerPoint presentation, LabVIEW-based FPGA software, and an embedded learning board, as shown in Fig. 5.

Fig. 5 *Instructional package on embedded systems and applications*

3.2 Embedded Learning Board Development

The main device used in the embedded learning board is a Melon S3 FPGA manufactured by Q-Wave Systems Co., Ltd. as shown in Fig. 6. The main device of the Melon S3 FPGA is the Xilinx Spartan 3E FPGA chip with a capacity of 500,000 gates. It has block RAM 360Kb on the PQG208 chassis with 208 pins. The total number of usable pins is 28 PINs x 2 ports = 56 PINs. It works with the chip Espressif brand microcontroller, model ESP-WROOM-02, which works at the 2.4GHz frequency band. It is an SoC (Systems on Chip) module that combines MCU+WiFi within a single chip. In addition, there is a 4MB Flash memory, which is designed to be a space for storing files in 2 parts: the first part is the bit files storage area of the FPGA (3MB), and the second part is the area to store firmware of the MCU (1MB), which performs functions manage downloading and connecting to the FPGA. The board comes with a USB-UART bridge circuit using a Silicon Labs brand chip model CP2104. The Melon S3 FPGA board structure is shown in Fig. 7. It can be plugged into a computer to download programs and debug programs immediately.

Fig. 6 *The Melon S3 FPGA*

The specific features of the Melon S3 FPGA are as follows: 1) OTA (Over-The-Air) Download .bit file to FPGA over the WiFi. 2) Xilinx Spartan 3E FPGA (PQG208) - 500K gates, (73Kb Distributed RAM, 4 Digital Clock Manager (DCM), 20 Mutipliers (18x18), 360 Kb Block RAM). 3)Onboard USB-UART (Silicon Labs) CP2104 for Configuration, Debugging and Power. 4) MCU WROOM-02 (ESP8266), WiFi 2.4GHz + 32-bit MCU (Arduino Compatible) Clock 80MHz, 50KB RAM, Integrated TCP/IP protocol stack. 5) Flash 4MB SPI Flash which is 1MB for MCU Firmware and 3MB for FPGA Bit space. 6) 8 Users LEDs, 4 DIP Switch user buttons, 1 Reset button 7) Onboard FPGA clock 50MHz 8) GPIOs 56 PINs 3.3V Tolerant-40 PINs x2 (Raspberry Pi 40 PINs Compatible) and 9) JTAG Port (*Optional for Program/Debugging). The position details of each device on the Melon S3 FPGA are shown in Table 1. The input/output devices of the embedded learning board are designed to support all digital circuit design experiments without connecting wires because all devices have addresses connected to the Melon S3 FPGA.

Table 1 *The position details on the Melon S3 FPGA*

Position	Reference	Description
1	JTAG Port	Programming & debugging using Xilinx ISE Software
2	FPGA	Xilinx FPGA Spartan 3E 500K
3	LEDs	x8 LED (Green)
4	DIP SWs	x4 DIP Switches
5	PWR LEDs	3.3V Power LED (Red)
6	XStop	FPGA code will STOP if the jumper is added, using this jumper as an FPGA stop
7	Status LED	User define LED (Green) at GPIO15 of ESP8266
8	MCU	WiFi SoC (ESP8266) Flash 4MB Version
9	Oscillator	ABRACON 50 MHz onboard oscillator (50ppm)
10	LED1	User define LED (Green) at GPIO2 of ESP8266
11	Reset SW	Reset button for ESP8266
12	TX/RX	TX/RX jumper of ESP8266 and USB CP2104
13	USB IC	CP2104 UART to USB IC
14	USB LED	USB Plug-in LED Status (VUSB)
15	DONE LED	FPGA Status LED if .bit file downloaded to FPGA without error
16	Vin 5V	External Power supply +5V can power the board from this pin
17	TX/RX	TX/RX LED Status of USB IC (CP2104)
18	USB Connect	USB Connector for +5V input for powering the board or Programming/Debug

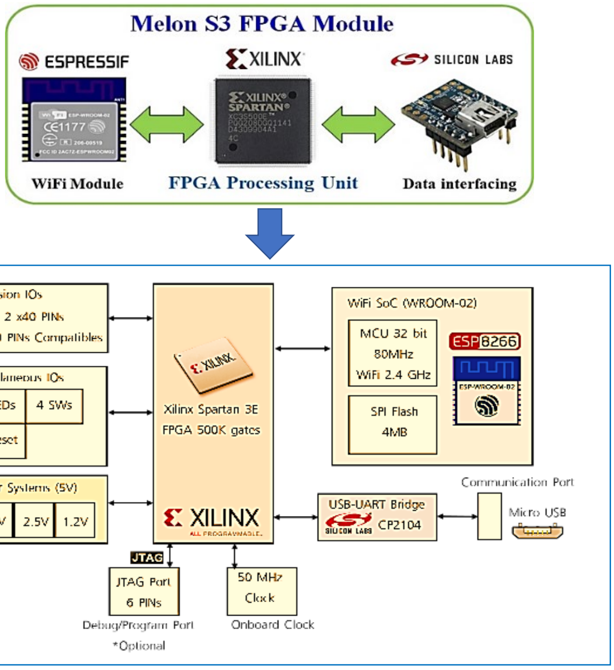

Fig. 7 *The Melon S3 FPGA board structure*

Design of all input/output devices of the embedded learning board as shown in Fig. 8. The researcher designed it to be able to use all equipment covered in the digital circuit design course. All input/output devices are connected to the Xilinx Spartan 3E. Students can easily set the device's address when they want to use a device. No wiring is required with an external general-purpose board. This makes it possible to reduce errors from connecting circuit wires. Details of the input/output device include: 1) 5V, 1-3A power supply, can choose from 3 types of power supply: USB Type-C port, micro USB port, and 2-pin connector, 2) Buzzer, 3) Output relay 2 channels, 4) Input optocoupler 4 channels, 5) Output 7-segment 8 digits, 6) Output LED 8 channels, 7) Input DIP switch 8 channels, 8) Input button 4 channels, 9) SPI communication port 2 channels, 10) UART communication port, 11) I2C communication port, 12) 16-character 2-line LCD and can adjust the screen intensity. All input/output devices are connected to Xilinx spartan 3E's GPIO and can support future CPU replacement because the embedded learning board can replace the old CPU with a new one.

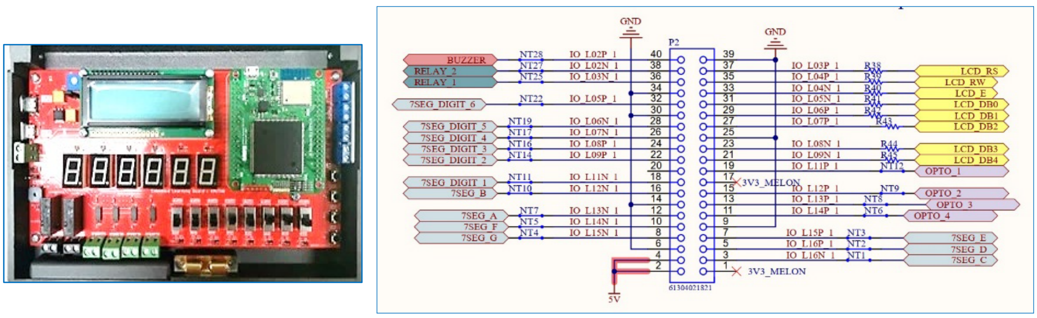

Fig. 8 *Embedded learning board and I/O interfacing port*

3.3 Software Development for Embedded Learning Board

Embedded learning board supports programming in many languages such as VHDL/Verilog using Xilinx ISE WebPACK Design Software, MATLAB/Simulink this requires additional installation of HDL Coder/HDL verifier, and for learners who are not good at programming with text programming, development in LabVIEW language is also supported by an additional installation of FPGA Toolkit. In this research, the researcher used LabVIEW as the basis for an instructional package that was developed using Xilinx ISE WebPACK design software, as shown in Fig. 9., which supports free Spartan 3E FPGA development. LabVIEW is the basic software for Bachelor of Engineering students, the Department of Electrical Engineering, the Department of Information and Communication Engineering, and the Department of Robotics and Intelligent Electronics Engineering. Faculty of Engineering and

Industrial Technology at Phetchaburi Rajabhat University. This makes learning possible continuously and can be applied to other related subjects in line with Industry 4.0 guidelines.

Fig. 9 *Programming for embedded learning board*

The design and development of an instructional package use LabVIEW-based FPGA software as the main teaching method as shown in Fig. 10. It is a software that can be used to efficiently design FPGA systems. It has an IP library, a high-fidelity simulator, and debug features (Pratik, et al. 2023). Students can also create FPGA VIs that include I/O access using LabVIEW logic, which students can define to modify the specified hardware properties themselves. It also has many built-in signal processing algorithms and it can be used with hardware description language as well. The input/output devices of the embedded learning board are internally wired to connect to all FPGAs, without the learner needing to connect external wires. This reduces errors in hardware connections and each input/output device has an assigned device address. When students want to connect to any device, they can refer to the location immediately. The connection of the embedded learning board to software as shown in Fig. 11.

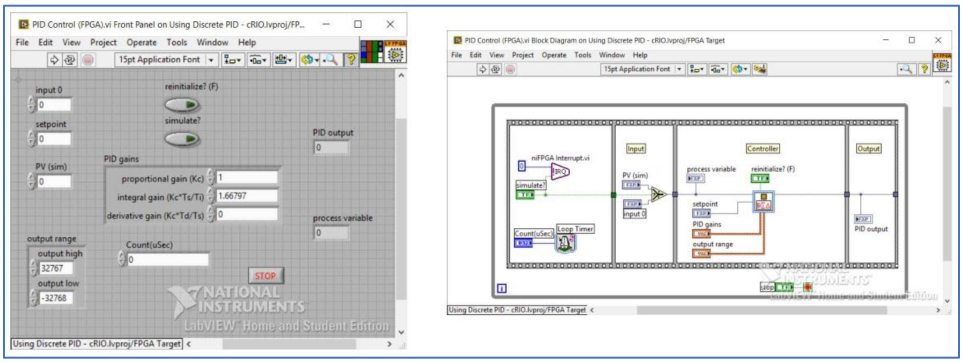

Fig. 10 *LabVIEW-based FPGA software*

Finally, the development of a blended laboratory-based instructional package for embedded system applications includes a teacher's manual, PowerPoint presentation, LabVIEW-based FPGA software, embedded learning board, and achievement test and questionnaires evaluated by 5 experts. The developed instructional package was tested with a sample of undergraduate students enrolled in the digital circuit design course, at the Department of Information and Communication Engineering, Faculty of Engineering and Industrial Technology at Phetchaburi Rajabhat University, Phetchaburi Province in Thailand, totaling 32 students. Then the research data were collected and analyzed to find the mean, percentage, standard deviation, and efficiency using academic achievement tests and questionnaires. (Ruangsiri & Akatimagool, 2019).

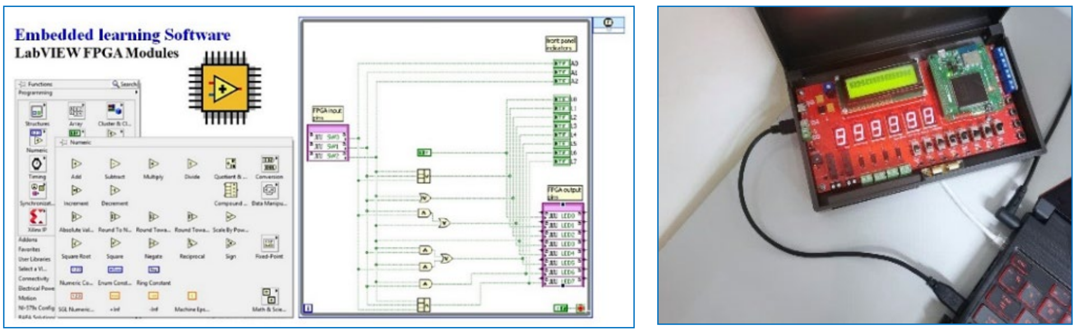

Fig. 11 *Software for embedded learning board*

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4. Research Results

The development of a blended laboratory-based instructional package for embedded system applications was then implemented. The results of the research include four parts of quality; 1) The evaluated results of quality of the instructional package such as the teacher manual, instructional tools, and achievement tests, 2) The evaluated results of quality from the PPED blended laboratory-based learning model, 3) The efficiency results of the developed instructional package using the PPED blended laboratory-based learning model, and 4) The students' satisfaction using the developed of a blended laboratory-based instructional package for embedded system applications.

Table 2 *The evaluation results of the instructional packages*

Topics	Appropriate level		
	Mean	S.D.	Interpret
1. The PPED-based teacher's manual			
1) Related to the lesson objectives	4.20	0.75	High
2) Accuracy of content	4.00	0.63	High
3) Promote understanding and learning	4.60	0.49	Very High
4) Appropriate graphics and images	4.80	0.40	Very High
5) Motivate students to be motivated	4.20	0.40	High
Total value	4.36	0.53	High
2. Simulation program			
1) Reflect the students' educational level	4.20	0.40	High
2) Simulation accuracy	4.20	0.75	High
3) Easy and convenient to use	4.60	0.49	Very High
4) consistent with the lesson content	4.20	0.40	High
5) Promote theory and practical learning	4.60	0.49	Very High
Total value	4.36	0.51	High
3. Experimental package			
1) Consistent with the lesson content	4.40	0.49	High
2) Accuracy of operation	4.20	0.40	High
3) Appropriate amount and quality	4.80	0.40	Very High
4) Appropriate design and construction	4.80	0.40	Very High
5) Easy and convenient to use	4.60	0.49	Very High
Total value	4.56	0.44	Very High
4. Measurement and evaluation			
1) Related to the lesson objectives	4.00	0.00	High
2) Clear and understandable questions	4.60	0.49	Very High
3) Appropriate quality of the exam	4.20	0.40	High
4) Appropriate number and time of testing	4.00	0.63	High
5) Measurement of both knowledge and skills	4.60	0.49	Very High
Total value	4.28	0.40	High
Total average value	4.39	0.47	High

4.1 The Evaluation of the Instructional Packages

The development of a blended laboratory-based instructional package for embedded systems and applications consists of four parts: 1) The PPED-based teacher manual on embedded systems and applications, 2) the Simulation program using LabVIEW FPGA, 3) the Experimental set using an embedded learning board and learning worksheets, and 4) Measurement and evaluation with Likert scale questionnaire. It can be seen that the overall instructional package was highly appropriate and had an average value of 4.39, with an S.D. of 0.47, as shown in Table 2.

4.2 The Evaluation of the PPED Blended Laboratory-Based Learning Model

The results of the evaluation by 5 experts show that the qualitative data of the developed PPED blended laboratory-based learning model was highly appropriate and had an average value of 4.26, with the S.D. of 0.40, as shown in Table 3. It can be seen that the developed PPED-based learning activities can be used in both theory and practical teaching on the embedded system and applications. The assessment tools can be used efficiently in measuring and evaluating in real situations.

Table 3 *The evaluation results of the PPED blended laboratory-based learning model*

Topics	Appropriate level		
	Mean	S.D.	Interpret
1) The learning process focuses on learner and 21st-century skills.	4.00	0.63	High
2) The processes of the learning process are interrelated.	4.00	0.00	High
3) Suitable for learning embedded systems and applications	4.60	0.49	Very High
4) Developed learning activities can be used in practice.	4.60	0.49	Very High
5) Learners work in teams according to objectives.	4.00	0.00	High
6) Learners can do research by themselves independently.	4.20	0.40	High
7) Appropriate S-PPED-C model for blended laboratory-based	4.20	0.40	High
8) Promote learners to understand complex and difficult content	4.40	0.49	High
9) Assessment tools can be used in measuring real situations.	4.60	0.49	Very High
10) Tests are appropriately related to learning objectives.	4.00	0.63	High
Total average value	4.26	0.40	High

4.3 The Efficiency of the PPED Blended Laboratory-Based Learning Model

The developed PPED blended laboratory-based learning model was implemented by using a sampling group of 32 bachelor learners registered in the digital circuit design course, at the at the Department of Information and Communication Engineering, Faculty of Engineering and Industrial Technology at Phetchaburi Rajabhat University, Phetchaburi Province in Thailand. Before and after lessons learning, learners were required to the pre-test and post-test respectively. The test is designed to align with behavioral objectives. A total of 60 tests, covered every lesson, and each test was evaluated by experts to determine its IOC. The IOC ranged from 0.80 to 1.00, with an overall average of 0.92, indicating that all tests can be used in teaching and learning. The collected data was analyzed for efficiency and validated by using the Meguigans theory as shown in Table 4. We found that the developed PPED blended laboratory-based learning model was efficient with the Meguigans value equal to 1.02 according to the Meguigans formula (if the mean value is more than 1.0, the effective learning and teaching are considered validated).

Table 4 *The efficiency results of the learning model based on the Meguigans criteria*

Topics	Full Score	Minimum Score	Maximum Score	Mean Value	Meguigans Value
Pre-test	60	32	10	18.44	1.02
Post-test	60	54	36	43.38	

Then the scores from the tests for each unit of study and academic achievement tests were analyzed to find the efficiency level according to the standard criteria (E1/E2) specified as 70/70 as shown in Table 5. Which results in the analysis of test scores in each learning unit totaling 4 learning units. There is a process efficiency level value (E1) has an average value of 74.38 percent and the results of the analysis of scores from the academic achievement test. Efficiency in results (E2) has an average value of 72.29 percent, higher than the standard criteria of 70/70 percent. It shows that the teaching and learning process encourages students to participate in teaching and learning activities. Able to create new knowledge efficiently due to the developed integrated science teaching model. Encourage learners to participate in teaching and learning activities and perform tasks on their own. There is a presentation and exchange of knowledge that gives students skills and the ability to apply them effectively. Especially the development of embedded system technology.

Table 5 *The efficiency results of the learning model based on the E1/E2 criteria*

Topics	The score for each unit				Total score	Post-test
	Unit 1	Unit 2	Unit 3	Unit 4		
Full score	15	15	15	15	60	60
Number of samples	32	32	32	32		
Everyone's total score	346	372	354	356	1428	1388
Average score	10.81	11.63	11.06	11.13	44.63	43.38
Average percentage score	72.08	77.50	73.75	74.17	74.38	72.29
E1/E2			74.38			72.29

Table 6 *The quality results of student satisfaction with the instructional package*

Evaluation topics	Appropriate level		
	Mean	S.D.	Interpret
1) The S-PPED-C activity plan is integration teaching.	4.53	0.60	Very High
2) The time and process spent learning activity	4.00	0.65	High
3) The learning and teaching methods are diverse.	4.05	0.69	High
4) The learning and teaching activities are appropriate and diverse.	4.11	0.72	High
5) The measurement and evaluation are appropriate.	4.16	0.67	High
6) The lesson content is consistent with the lesson objective.	4.05	0.60	High
7) The lesson content is accurate and complete.	4.11	0.64	High
8) The content is appropriate for the learner level and difference.	4.53	0.68	Very High
9) The arranging and managing of content are appropriate.	4.21	0.69	High
10) The language and images are appropriate.	4.63	0.48	Very High
11) The simulation program is consistent with lesson objectives.	4.00	0.56	High
12) The media can encourage self-learning and long-lift learning.	4.58	0.49	Very High
13) The design of the simulation program is appropriate.	4.63	0.48	Very High
14) The simulation program promotes theory and practical learning.	4.16	0.67	High
15) The simulation program can be used correctly and completely.	4.16	0.59	High
16) The experimental package is consistent with lesson objectives.	4.32	0.46	High
17) The design of the experimental package is appropriate.	4.63	0.48	Very High
18) The experimental package is appropriate in amount and quality.	4.58	0.49	Very High
19) The experimental package is accurate and precise.	4.21	0.69	High
20) The experimental package encourages learners to have skills.	4.53	0.50	Very High
21) The assessment is related to the lesson objectives.	4.11	0.79	High
22) The questions are clear and understandable.	4.32	0.57	High
23) The quality of the exam is appropriate.	4.00	0.65	High
24) The number and time of testing is appropriate.	4.05	0.76	High
25) The assessment methods encourage both knowledge and skills.	4.11	0.55	High
Total average value	4.27	0.61	High

4.4 The Quality of Student Satisfaction for Instructional Package

Considering the results of the satisfaction analysis of 32 students, it can be seen that students are satisfied with learning with the developed teaching package through the PPED blended laboratory-based learning model. The overall suitability for use in a high level of the PPED blended laboratory-based learning model with a mean value of 4.27 and an S.D. value of 0.61, as shown in Table 6. In addition, it was found that the developed teaching packages were created from the integration of modern technology. This makes it an educational innovation that helps make teaching and learning more effective. Additionally, from the interview data, some students commented that the PPED blended laboratory-based learning model allowed students to become more involved in learning activities compared to traditional learning formats. This learning model has many steps and details. As a result, some lessons took longer than usual, students did not understand some of the lesson content. Teachers should reduce the amount of content in some lessons and develop teaching materials into self-learning or free-time learning, both inside and outside the classroom or online learning.

5. Conclusions

This research paper presents the development of a blended laboratory-based instructional package for embedded systems and applications supporting 21st-century education. The evaluation results show that 1) the quality of the instructional package was suitable at a high level, 2) the quality of the PPED blended laboratory-based learning model was suitable at a high level, 3) the efficiency of the PPED blended laboratory-based learning model was suitable at a standard level according to the criteria of Meguigans and E1/E2 theory, and 4) the quality of student satisfaction for an instructional package was suitable at a high level. However, the teaching and learning of electrical and electronics engineering courses should be consistent with 21st-century skills and the Industry 4.0 era to support the ever-increasing changes in technological innovation. Therefore, the development of modern teaching requires the integration of technology with various teaching formats and appropriate learning activities. It is necessary and important for the role of education in the future.

Suggestions for research are collected from the discussion and interview information. Some teachers and experts gave their opinions and suggestions that the teacher's manual and learning activity plan do not have enough details to clearly explain to teachers the teaching process according to the PPED blended laboratory-based learning model, resulting in incomplete teaching and learning or sometimes taking more time than the usual plan. However, the teaching media package has a variety that can be used according to the differences of the students and can promote lifelong learning skills. In the development of the next work, the researcher should analyze the gap in occupational professional competency and make skill mapping to up-skill or re-skill by using a learning center that is consistent with the needs of the industrial sector.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Surasak Inchan;* ***data collection:*** *Somsak Akatimagool;* ***analysis and interpretation of results:*** *Surasak Inchan, Somsak Akatimagool;* ***draft manuscript preparation:*** *Surasak Inchan, Somsak Akatimagool. All authors reviewed the results and approved the final version of the manuscript.*

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